

Quantification of Posterior Globe Flattening: Methodology Development and Validation

S. B. Lumpkins¹, K. M. Garcia², A. E. Sargsyan², D. R. Hamilton², M. D. Berggren³, E. Antonsen¹, D. Ebert²

¹Harvard-MIT Division of Health Sciences and Technology, Cambridge, MA, ²Wyle Integrated Science and Engineering, Houston, TX, and ³Purdue University, West Lafayette, IN.

Introduction

Microgravity exposure affects visual acuity in a subset of astronauts, and mechanisms may include structural changes in the posterior globe and orbit. Particularly, posterior globe flattening has been implicated in several astronauts. This phenomenon is known to affect some terrestrial patient populations, and has been shown to be associated with intracranial hypertension. It is commonly assessed by magnetic resonance imaging (MRI), computed tomography (CT), or B-mode ultrasound (US), without consistent objective criteria. NASA uses a semi-quantitative scale of 0-3 as part of eye/orbit MRI and US analysis for occupational monitoring purposes. The goal of this study was to initiate development of an objective quantification methodology for posterior globe flattening.

Materials and Methods

Image analysis and mathematical tools were tested on objects with a known radius to verify accuracy, reproducibility, and error-free operation. The methodology was then tested using astronaut eye US images from a random sample of 36 preflight, 10 in-flight, and 31 post flight US examinations (including pre-and post-flight study pairs of 23 astronauts). Semi-quantitative scores of globe flattening (on a scale of 0-3) were compiled from the corresponding imaging reports. All images were blinded before analysis. Several approaches to quantifying “flatness” were recognized, including determination of the radius of posterior globe curvature, the span of the flattened area, and others. However, this preliminary study focused on two metrics based on a series of points outlining the vitreo-retinal interface on a digital US image. The ‘radius of curvature’ metric was based on least-squares regression. The ‘flatness error’ metric was defined as the sum of the square of the error between outlined points and the regression line that defines the major axis of the eye contour, normalized by the number of points. Both metrics were used to determine the average globe flatness in preflight, inflight, and postflight images. The percent change in flatness inflight vs. preflight, as well as postflight vs. preflight was also assessed. In a separate analysis, differences were considered between long-duration and short-duration subsets. A one-sided tolerance test allowed assessing the percentage of the population that would be expected to have any degree of globe flattening based on the average percent change in eye curvature postflight vs. preflight (n=23).

Results

No statistically significant differences in average globe flatness were found between preflight, inflight, and postflight eye images using either the scores or quantitative metrics when long and short duration data were pooled. When each eye was considered individually based on the scores of globe flatness, 30.4% of left eyes (OS) and 21.7% of right eyes (OD) became flatter postflight vs. preflight. Using the radius of curvature metric, 52.2% (OS) and 43.5% (OD) became flatter postflight vs. preflight. In long-duration astronauts only, 33% (OD) and 16.7% (OS) were found to be flatter postflight based on the scores, and 67% (OD) and 50% (OS) respectively based on the radius of curvature, likely because small changes were missed by subjective scoring. Tolerance testing using the radius of curvature data revealed with a 95% confidence that 45% of left eyes and 47% of right eyes will have some degree of globe flattening as a result of spaceflight. Despite clear trends, the differences found in globe flatness postflight compared to preflight using either the scores or quantitative metrics were not statistically significant. The metrics were not significantly different between OD and OS, or between long- and short-duration subjects.

Conclusion

The image analysis and mathematical tools of this study appear effective in assessing the shape of the posterior globe in the context of space flight, and form a basis for automated image analysis. In this sample, they showed trends similar to ratings by highly trained sonographers. Future work will focus on these and other metrics in the context of the imaging techniques, including standardized image acquisition and strict definition of measurement area. Objective determination of flattening appears to be a promising monitoring tool in astronauts and in some clinical populations; this and future techniques can be easily adapted for other tomographic images such as MRI or CT.